From: Schimmel, Lanny [lanny.schimmel@voith.com]
Sent: Monday, October 30, 2006 5:41 PM
To: Asuquo, Gibson
Cc: Heinzmann, Helmut; Linden, Volker; Begemann, Ulrich
Subject: GO10622: Final Report: Proprietary Feasibility Study of a Continuous Process for Displacement Dewatering

Dear Mr. Asuquo,

Mr. Helmut Heinzmann from Voith Paper Holding GmbH & Co. KG ("Voith") has asked me to contact you on his behalf regarding the publication of the Final Technical Report in the above-referenced matter. There appears to have been some confusion as to whether Voith authorized the release of the information contained in the report.

Voith hereby authorizes release of the report to the public.

Voith has appreciated the assistance of the U.S. government with this project. Should you have any questions or require further action from Voith, please do not hesitate to contact me.

Lanny M. Schimmel
Corporate Counsel

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Development of A Continuous Process for Displacement Dewatering Final Report By Dave Beck

Acknowledgement:

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Disclaimer:

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the Department of Energy

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Executive Summary

Note: To best understand this project's accomplishments, it is recommended that this entire document be read. This project deals with an entirely new novel method for processing paper that is unpublished. The most relevant publications were published about 12 years ago so this general field is unknown except by a few people in the industry.

The subject of this contract was to investigate the viability of a new process for dewatering paper called displacement pressing. The term "displacement pressing" was coined in the 1980s by researchers to describe a paper dewatering process where air is blown through a sheet of paper while it is being pressed. It was shown at that time that the combination of air and low pressing force could dramatically increase both sheet bulk and sheet solids which in theory would translate into huge savings in energy and fiber consumption.

But there was a catch. Although the research results were dramatic, no one could figure out a commercially viable process to carry out displacement pressing. All research work had been done with batch processes, and there was no obvious way to convert these processes into a continuous process. By the end of the early1990's no one was researching in this area because no continuous process existed.

Recently we proposed a new method to carry out displacement pressing. Our process uses special pressing fabrics and a special 4 roll press that we call a "Beck Cluster Press" or BCP. The BCP provides a pressurized atmosphere that acts on a moving web of paper and fabrics. The special fabrics designed for this process use this atmosphere to press the sheet and at the same time, these special fabrics force air through the sheet to carry out displacement pressing.

Because of the complexity and cost of building the first functioning BCP, a simple simulator was built to confirm and study the process. Although results from this simulator were extremely favorable, financial times were hard in the paper industry. We are grateful for the DOE contract that allowed us to continue research that showed the tremendous benefits of displacement pressing. Specifically, accomplishments from the DOE contract are as follows:

1. A narrow (5" wide sheet) lab Beck Cluster Press (BCP) was started up, and made operational. This press accepts hand sheets and displacement presses them at conditions that duplicate commercial conditions for dwell time, and pressure.
2. The lab BCP machine was used to verify simulator results. Results showed the lab BCP gave paper dryness that exceeded simulator results for dryness.
3. Sheet samples were obtained for several paper grades. These samples were pressed conventionally (shoe and roll presses) and with the lab BCP. Results showed significant gains in bulk (5-48%) compared to commercially pressed sheets while producing similar or higher dryness. These results verified the predictions of the earlier research papers.
4. Sheet bulk exceeded the Agenda 2020 goal a 7% increase. This increase in bulk was reported by Agenda 2020 as being worth about 3 billion dollars per year in fiber savings. Potential energy savings due to dryness savings could be worth $1 billion per year. However energy savings and fiber savings are inter-related so while savings are likely in both energy and fiber at the same time, increasing one will cause the other to decrease.
5. Based on the significant results of small-scale BCP trials, a 1m pilot BCP press stand was built to determine scalability of the process.
6. 1m pilot press stand was started up. This machine was shown to hold design pressure. Drive issues however prevented operation at operating speed and pressure during the contact period. Improvements to the drive system since the end of the DOE contract have allowed us to reach operating pressure and speed.
7. The last DOE objective of passing paper through the 1m BCP was not reached due to drive issues and the desire to study and qualify sealing systems. All other original objectives and the added objective (by contract revision) of this ambitious project have been met.
8. Several paper companies have showed interest in helping us commercialize this process. Interest is so high that these companies appear willing to invest in further development.

Background

We first became aware of displacement pressing through discussions with Nai Chang at the former Institute of Chemistry (IPC) in Appleton Wisconsin. Nai in informal discussions described the amazing results he was obtaining using compressed air to aid mechanical pressing. Nai had reasoned that compressed air could aid water removal just like steam was aiding water removal in impulse drying.

Nai's pioneering work prompted Douglas Warren to write in TAPPI Journal in 1986 (1) that "A brief pulse of modestly pressurized air, applied at mid nip while the sheet is compressed causes the free water to move out of the sheet and into the felt. Using a press simulator, we have achieved over 65% dryness in milliseconds at room temperature." But he also said "…practical implementation is probably quite some time away"

After the move of IPC to Atlanta, Professor Jeff Lindsay (2) took up the project. Jeff did perhaps the best job of researching, studying and describing displacement pressing. He studied the process using an MTS machine and a porous piston. The MTS machine would force a porous piston to compress the sheet at high speed. While compressed, air was passed through the sheet to improve dewatering. Despite the many problems Jeff had, he showed that high solids and bulk could be obtained with displacement pressing. But although his results were very impressive he could only process one piece of paper at a time. His process was far from commercialization but his groundbreaking research showed that displacement pressing had great potential.

Despite the gains Jeff and others reported (3,4) there were no methods available to do displacement pressing on a continuous basis. To the few researchers that follow papermaking physics, it became obvious that displacement pressing could make a quantum jump in sheet bulk, but there was no clear way to do it. The financial gains from a displacement pressing process could be substantial. Without a process the field of displacement pressing became an obscure laboratory curiosity.

After reading and hearing these reports over many years it eventually occurred to the author that there might be a way to make a displacement press. The author's displacement pressing concept, described in US patents 6,161,303 and 6,416,631 (among others) is shown and described below.

How the Beck Cluster Press (BCP) Works

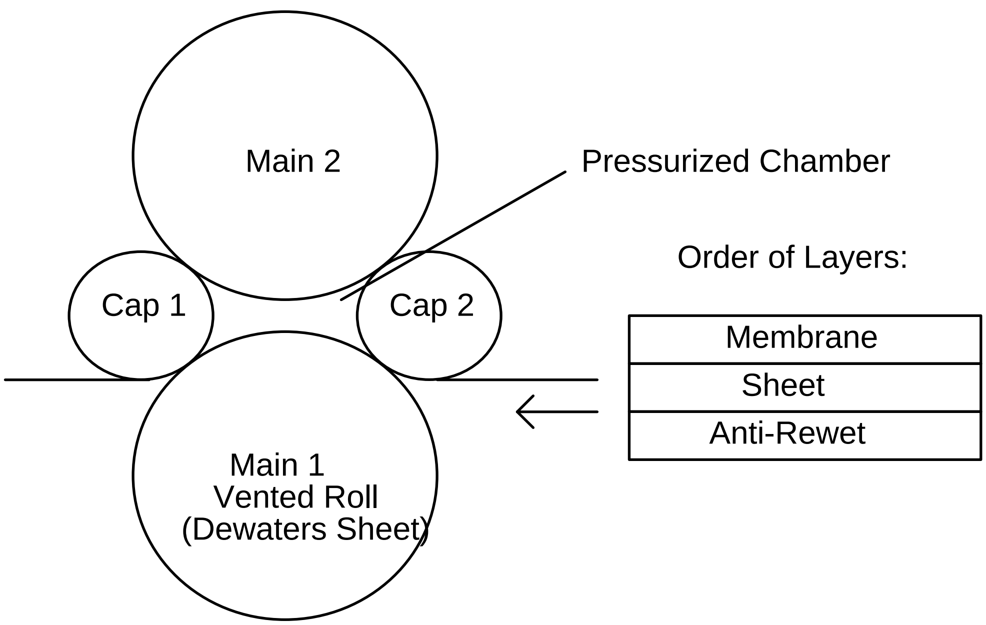


Figure 1

In this diagram, 4 press rollers are nipped together so they form an enclosed area call a 'chamber'. With the proper end seals for the roll ends, the chamber can be sealed off and pressurized with air. As shown in the diagram, our convention is to call the large rolls "main rolls" and the smaller rolls are called cap rolls. The main rolls, with their large surface area, support most of the air pressure loads. The lower main roll in this diagram is vented, meaning that its surface is porous and allows airflow.

The function of the cap rolls is to enclose the chamber and to provide seals for the entrance and exit of the webs. The cap rolls are smaller than the main rolls which reduces the arc and thus the load on them.

It is a property of the cluster configuration shown that all rolls turn without slip. In simple terms, this means that if you turn one roll, all the others will rotate together. This property allows one to pass a web through the press nip into the pressurized chamber without the wear of sliding seals. The nips form rotary seals which contain the air pressure yet allow easy passage for the web to pass through the pressure chamber.

As shown, the web that passes through the pressure chamber is made up of at least 3 elements. The upper element is called the membrane and it has two functions. The membrane’s first function is to press the sheet which occurs due to the high pressure on the chamber side. The pressure difference across the membrane causes it to act like a piston and press the sheet. Since the pressing action is caused by air pressure acting on a flexible membrane, the mechanical pressing is very uniform.

The second function of the membrane is to allow air flow through it. The membrane is constructed to be slightly permeable – actually much less permeable than any current pressing fabric. Because of this permeability and the high chamber pressure, a small amount of air passes through the membrane and sheet. Thus, the second element of displacement pressing is fulfilled namely that of allowing air to flow through the sheet while pressing.

Underneath the membrane is the sheet of paper. The mechanical pressure from the membrane causes the sheet to be consolidated. In practical terms, the pressure on the sheet consolidates the voids in the sheet making its flow properties more uniform. In addition the action of mechanical pressing and airflow causes water to be released from the sheet and this water is removed by the moving air stream. The airflow pushes the water into the next layers below the sheet.

The third layer in the web beneath the sheet is the ‘anti-rewet’ layer. This layer accepts water from the sheet and helps to isolate that water to prevent it from returning back to the sheet. This isolation is accomplished by the airflow, which continues after the water leaves the sheet. The airflow breaks the capillary connections between the sheet and the removed water. It also moves the water away from the sheet. The air flow through the anti-rewet layer makes it difficult for water to re-connect and rewet the sheet of paper after the sheet leaves the displacement press.

A very unique feature of displacement pressing is the ability to reduce sheet rewet. In normal wet pressing, water is pressed out of the sheet, but that water remains near the sheet and is physically connected to it by wet capillaries. It is well documented that after the nip, sheet water can easily rewet the sheet due to wet capillary flow paths. This rewet reduces the ultimate dryness of the sheet and for this reason, rewet greatly increases the cost to dry the sheet. Displacement pressing however can greatly reduce this effect since air is pumped into the interface between the water and sheet. This air buffer greatly reduces rewet by increasing the distance between the water and sheet, and by blocking the capillary action that causes sheet rewet.

Discussion of Project Results

Bulk and Dryness gains

The financial justification for this process is closely tied to the bulk and dryness gains that it will produce. It was therefore, a major goal of this project to determine what gains are possible. Before this project was begun in earnest, a simulator was used to get an idea of the gains possible using a membrane to displacement press a sheet. Like prior displacement presses, our simulator was a batch process, allowing us to press one sheet of paper at a time. However our simulator did not use a piston. Rather, we used fabrics that did the pressing and allowed air flow. A schematic diagram of the simulator is shown below.

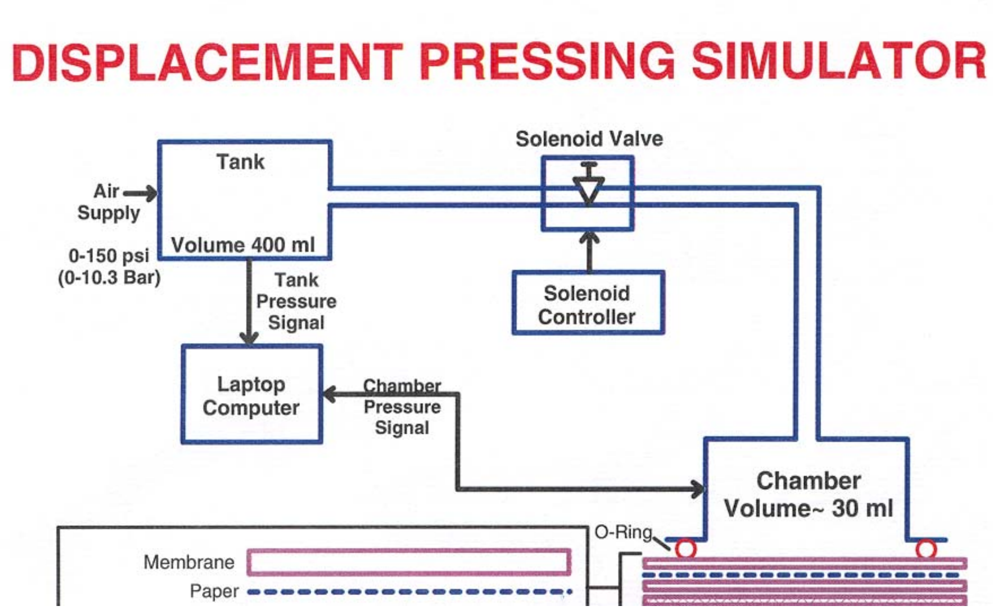


Figure 2

This simulator allowed us to develop and test fabrics on a small scale prior to building a larger continuous machine. Using this simulator, we were able to develop the following curves that show the relationship between sheet solids and bulk.

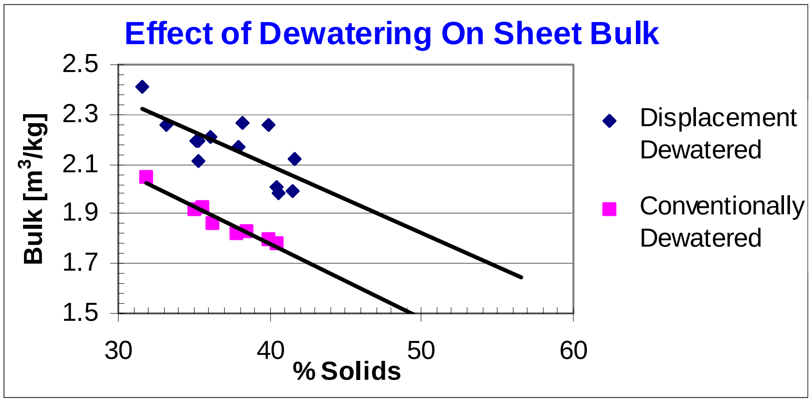


Figure 3

Figure 3 nicely illustrates the relationship we found that exists between bulk and dryness. The plot shows in general for conventional and displacement pressing, as dryness is increased, bulk is reduced. In other words, it is necessary to compact the sheet in order to remove water from it for both conventional and displacement dewatering. But the big news is that for similar solids, there is a large increase in bulk for the displacement dewatering process. Under our simulation conditions, displacement dewatering shows about 15% higher bulk than conventional dewatering. I believe that DOE decided to fund our project based on this finding. These findings were further verified through our hand sheet studies done under this contract.

Encouraged by these simulator studies, we designed and built a small lab BCP. The start of DOE funding was delayed, so this machine was largely built and assembled prior to the start of the DOE contract. DOE funds however were very useful in starting up and running this machine. Below is a photo of the lab press we built as an add-on to our pre-existing paper machine.

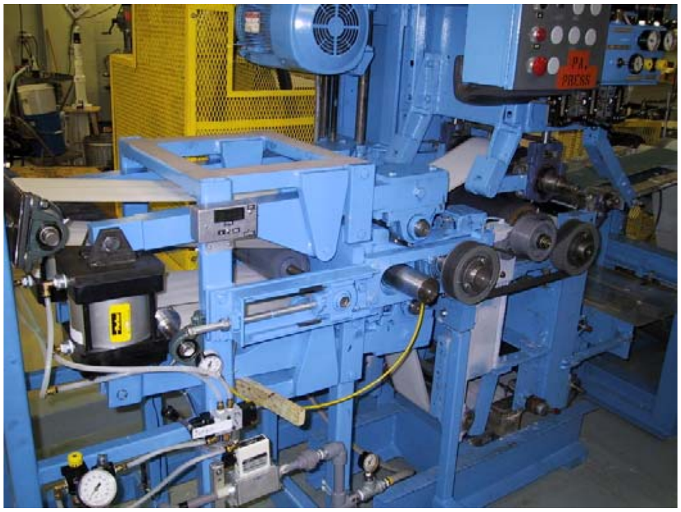


Figure 4

Schematically, the BCP press section is shown below. It is also described in US patents: 6,161,303 and 6,416,631 (among others)

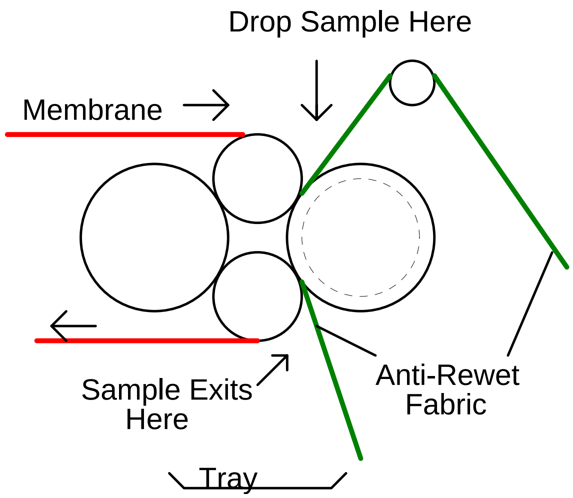


Figure 5

As shown, this press has two fabric runs. The membrane fabric wraps around the top cap roll, and joins with the anti-rewet fabric just before going into the pressure chamber. At the nip where the membrane and the anti-rewet fabrics joined, we could introduce hand sheet samples. The sheet would then travel through the pressurized chamber and then exit at the bottom of the chamber, dropping in the sample tray. Depending on the tests being done, we would either drop the sheet “as is” through the machine, or we would drop a sample “pocket” which contained the sheet. When using pockets, we made the pockets from membrane and anti-rewet material, with the sheet in between. We would wet up the pockets, add the sheet and then pass them through the machine. After pressing, the sample/ pocket would drop into the tray, and the sheet would be removed for further testing.

At this point a few comments are necessary about the BCP press nip. The roll diameters of this press are about 1/7th to 1/8th the diameter of an anticipated commercial machine’s rolls. Even with the small roll diameters, this press’ dewatering zone is very formidable. The effective dewatering nip length of this small press is about 5 inches. To put this nip length in perspective, the largest roll press in existence today has a nip length of up to 3 inches. Most commercial “Long Nip” shoe presses have nip lengths of about 10 inches. So this small press has a nip that exceeds all commercial roll presses, and is ½ the length of a shoe press. A commercial BCP would have a nip 7 times larger than our lab press, making BCP machines the longest nips in the world. Such a long nip means these machines have very long dewatering dwell times giving them tremendous high speed potential.

The first tests done on our BCP were tests to compare our BCP to our batch simulator and to determine the benefit of air flow during pressing. For this comparison, TAPPI hand sheets were passed through our press using two methods. In the first method, the sheet was displacement pressed and these results are denoted ‘Membr’ in figure 6 graphs. In the second method, a thin sheet of .001” thick Mylar was placed on the membrane to block the air flow, allowing only mechanical pressing. In both methods, the same air pressure was used, so the main difference between Mech and Membr is the flow of air in the Membr case.

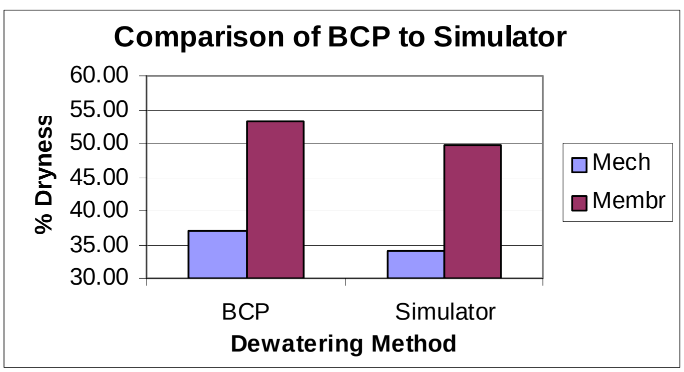


Figure 6

The above graph clearly shows the increased water removal due to air. By forcing air through the sheet, the sheet gave 15% higher solids for similar pressing pressures. This dramatic increase in solids is what makes displacement pressing so attractive

Similar tests were carried out on our simulator to try to duplicate the condition on our BCP press.

For these experiments, the paper, fabrics, and air pressures used were the same for the simulator and the BCP. Only the pressure pulse shape and the sheet handling after pressing were changed due experiment characteristics.

These graphs also show that both the simulator and BCP give similar overall results, with the simulator producing slightly lower dryness than an actual displacement press. There are two reasons for this. First, the simulator did not have the same pressure pulse as the actual BCP. The simulator air pressure pulse was affected by the opening and closing of a solenoid value, which is not the same as the pressure history seen by the sheet passing into the pressure chamber. Secondly, the sheet could not be removed as quickly from the simulator as from the BCP. It took some time to open the simulator and remove the sheet. In the BCP case, the sheet was immediately separated from the rewet layer after the nip. In any case, the results from the two pressing methods are close, and the lessons learned on the simulator appear to hold in general for the BCP. This includes lessons learned about bulk increases due to displacement pressing.

Based on these results, we surpassed our declared DOE ‘drop dead’ goal of attaining results similar to the simulator. With this goal reached, we were justified in starting phase 2 of the project - the design and building of a 1m machine of commercial scale. While the 1m press was being designed and built, we continued to test and refine our process and understanding using the lab machine.

A major goal of this project was to study the effect displacement pressing has on sheet properties. To make this comparison, commercial fine paper furnish was obtained from our commercial partner and from this hand sheets were prepared and pressed. The pressed sheets were then dried and compared with paper made on our partner’s commercial machine using the same furnish. The commercial machine used for comparison had 4 press sections, which means that the sheet was very well pressed before it was dried. For these trials, our partner became very involved. They supervised the pressing procedure and did all of the paper testing. From their testing they furnished the following data comparisons between commercial and BCP pressed paper.

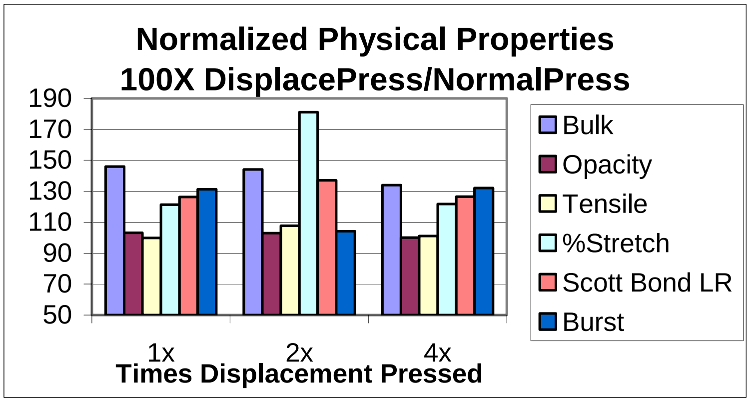


Figure 7

To make comparisons easier to see, the data has been normalized. That is, the data from the displacement pressed paper was divided by the commercial press data and the results were multiplied by 100. For example, in the above graph, the bulk of the once pressed displacement pressed paper, was about 48% higher than the bulk of the commercially pressed paper.

From this data we found the displacement pressed fine paper sheet to have:

1. Higher bulk (As much as 48% higher than commercially pressed paper.)
2. Higher stiffness (due to the sheet being thicker)
3. Slightly lower tensile strength (due to the lower consolidation of the sheet)
4. Stretcher sheet
5. Higher burst (Load is supported better due to the stretchiness of the sheet)
6. More permeable sheet
7. Similar or higher sheet solids

These findings are similar to the findings of earlier researchers using batch processes. The only difference was that the displacement pressed sheet showed higher than expected tensile strength. In general, the sheet property changes were improvements to commercial sheet properties.

For historical reference, one can compare these property changes to the changes seen for long nip shoe presses when they were first introduced. Similar sheet property changes were also seen however not to the high magnitude that this process accomplishes. These property changes justified a lot of paper machine rebuilds to shoe press technology. Now at this point in history it appears that we have an even stronger justification for implementing displacement pressing than we had for shoe presses. However each grade has its own requirements so these justifications will have to be looked at on an individual basis.

Up to this point, we had only studied room temperature sheets and its common practice to use elevated temperatures to increase dewatering efficiency. So it was decided to contact DOE to see if our contract could be expanded to allow us to study the effect of temperature on dewatering. DOE agreed to this and modified the contract accordingly.

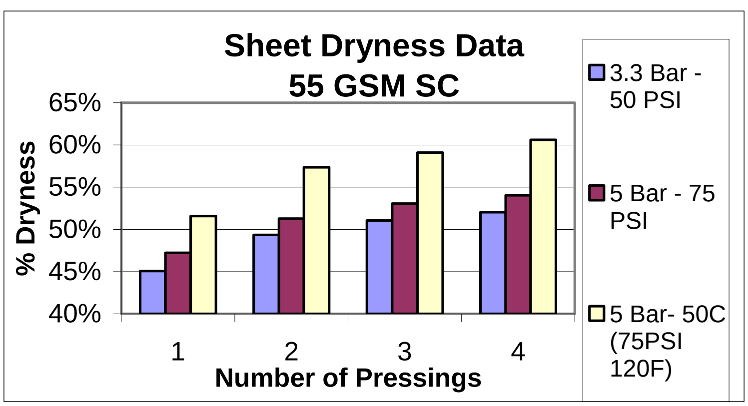


Figure 8

This graph shows the dramatic increase in solids obtained using elevated temperatures. The blue bar represents pressing a commercial super calendar (SC) furnish using 50 PSI chamber pressure of room temperature air. As shown, each pressing removes more and more water from the sheet. After 4 pressings, the sheet solids reach about 52%. This SC grade is more difficult to dewater than most paper furnish, so several pressings were used.

The red and yellow bars represent pressing the same sheet with higher pressure and at a modestly increased sheet temperature. Both increasing the pressure and the temperature have good effects on the sheet solids with the maximum sheet solids obtained exceeding 60%. This level of solids is higher than the solids levels seen for the commercial machine running this furnish. It was also found that the best way to increase sheet solids is to pre-warm the sheet before pressing.

Building a 1 Meter Wide Pilot Press Stand

During phase 2 of this project, we designed and built a larger scale BCP. The object was to design a press stand that had commercial sized elements in cross section but was of narrow width. All seals, roll diameters, and framing was to be of commercial size, but the machine width was to be limited to 1m width.

The objective for building this press stand was to test the BCP concept in commercial scale. Obviously, the best commercial test for this technology would be to develop a fully operating pilot machine that could make and process paper but this expensive. A pilot facility that makes paper cost 10's of millions of dollars to build and run. Building such an elaborate facility is a long term commitment. Rather than commit to this at this early stage of development, it was the goal of this project phase to build a test stand that could be used to test the new elements needed to make a BCP.

Design of the pilot press stand utilized the vast resources that Voith has for building paper machines. The Engineering group at Voith Paper – Appleton, worked in conjunction with Voith Fabrics to design the 1m machine. The design that was built is shown in the following diagram.

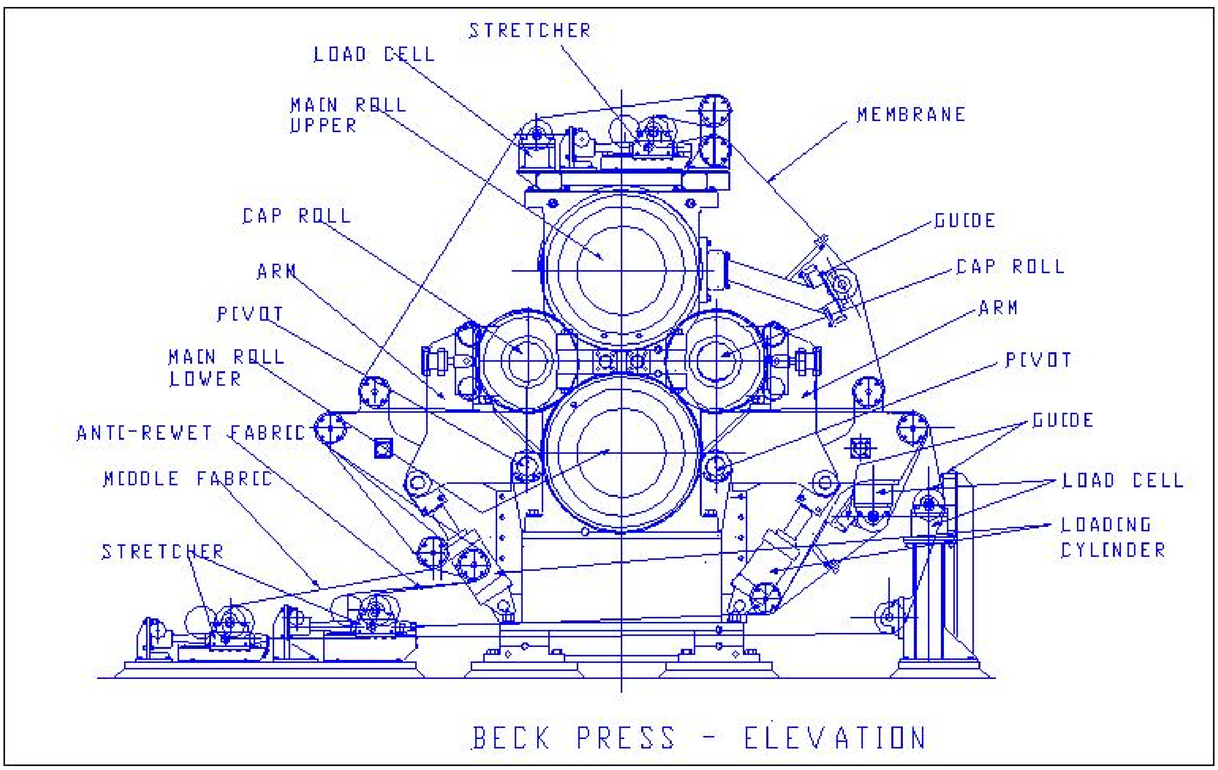


Figure 9

There were some significant Engineering problems that were encountered when scaling up the BCP to production sizes. Here a summary of the problems and the solutions:

Handling Large Loads

It was desired to build a pilot machine that approximates a commercial sized machine but to make such a machine, one must have some idea of what a commercial sized machine would look like. Since no one has ever seen a commercial sized BCP, a lot of ‘what if’ scenarios were evaluated. From these scenarios it quickly became obvious that conventional wisdom in roll press design does not directly apply to the BCP. For example, conventional wisdom says you increase roll diameter to increase roll strength. But as one quickly finds, increasing BCP roll diameter also leads to increased chamber area, and this leads to increases in loads. Thus gains in roll strength due to increased diameter are off set somewhat by increased load that also comes with increased roll diameter. Furthermore, roll cost also increases with roll diameter as well. So for many reasons, it is desired to keep roll diameters as small as possible.

Since the design of a large commercial machine was not our main objective, we settled on designing a machine using conventional rolls that could approximate a 100 - 200 inch wide commercial machine. The same size rolls of special design could support machine of perhaps up to 300” width. We reasoned that the first application of this technology would not be a wide machine, but rather most likely would be a more conservative width – less than 200 inches.

To handle the substantial press loads several methods were used.

1. Loads were concentrated in the dewatering zone where it does the most good, and reduced in other areas. This is the reason the main rolls are larger than the cap rolls. By having this difference in size, the pressure arc is increased on the main roll and reduced on the cap roll. Thus load is put where it does the most good.
2. Since the loads are highest on the main rolls, these rolls are tied together in the framework. In this manner, the largest loads are contained in the simplest framework possible.
3. The cap rolls are loaded into the main rolls via loading arms. Since the cap rolls support less load, it makes sense to make them the moving rolls
4. To adequately support the loads and maintain nip contact, extensive Finite Element Analysis (FEA) was done. The rolls in particular can deflect excessively under air pressure so it was necessary to design the rolls with thick enough shell and journals.

Other Design Considerations

In designing this press, it was decided to design it for the highest chamber pressures we could imagine. At the outset of the design, it was not known what pressures would be needed for best operation. Early simulations showed continued increase in sheet solids with increasing pressure. It was also seen that a highly filled sheet required higher pressures and longer dwell times to get effective dewatering. Based on these results, the press was designed to contain a pressure of 150 PSI (10 bar). Later, it turned out that 100 PSI or less is more likely the pressure needed for most grades. This reduction came as a result of better understanding of the process. Of course, the lower the pressure the better since the cost of the machine and its operation increases with increasing pressure.

Once the chamber pressure was set, a number of other press features were determined. For example, the press bearings were then sized to handle the loads from the chamber pressure at the design maximum speed of 5,000 feet/minute. The combination of speed, pressure and bearing life determined the bearing and journal sizes, which then determined the frame attributes.

One problem that cropped up early in the design was the fact that to handle the forces on the cap roll, it was necessary to use bearings that are similar in size to the cap roll itself. The large bearing size did not allow the cap roll bearings to be in the same plane as the main roll bearings. For this reason, the main and cap roll bearings had to be offset from each other, requiring longer and heaver journals for the main rolls. This increased the cost of the machine but it did pay off in allowing additional room to view and make modifications in the nip and end seal area.

Roll End Seals

An area of great interest in the design of this machine had to do with the design of the seals for the ends of the rolls. From the start, it was anticipated that this would be the most difficult part of the project. If a suitable seal could not be found, the rest of the project would not be practical, so intense effort was given to finding a suitable seal.

To seal the ends of the rolls, it was decided to make a seal that would push against the flat ends of the rolls. Our seal was designed to follow a closed loop path, crossing over between rolls at the nip points. We call this seal a dog-bone seal because of the shape. The approximate shape of the dog-bone seal is shown below.

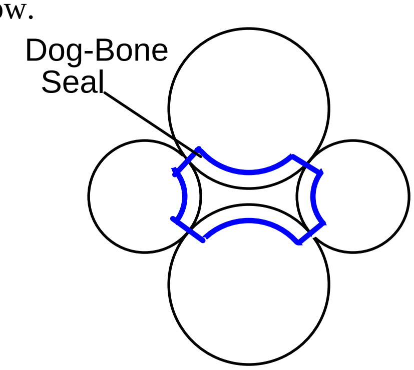


Figure 10

The dog-bone seal is part of a seal plate that closes off the end of the chamber. Such seals are needed on each end of the cluster press. With this basic idea in mind, we needed to define the types of materials needed for the seal, and the overall strategy for building it. As our initial DOE proposal shows, we fully intended to partner with a large seal company to design this critical seal. However, it eventually became apparent that our partnership was not leading toward a practical seal. Discussions with other seal companies also failed. Apparently there is not much call or experience or interest in developing seals that are not circular as we needed. We had to go it alone on this critical item.

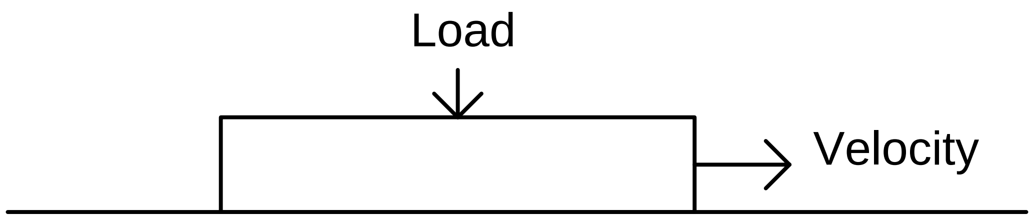
Seal testing started early in the project – even before the simulator was built. Hundreds of designs were tested with most being cast off as impractical. However, as time went on, it became apparent that certain features were necessary to make a practical dog-bone seal with long life.

For example, an important aspect of seal design is that it has low wear. Archard law describes the sliding wear that the dog-bone or any seal will experience.

'Archard' Law

$$\textbf{Wear Volume} = \textbf{K} \times \textbf{Slide Distance} \times \frac{\textbf{Load}}{\textbf{Hardness}}$$

$$\textbf{Wear Volume} = \textbf{K} \times \textbf{Pressure} \times \textbf{Velocity} \times \textbf{Time}$$



Conclusions:

- **Keep Contact Load to a Minimum**
- **Use Hard Surfaces**
- **Use Materials With High K**
- **I.E. Use slippery, tough materials**

Figure 11

The first conclusion from this law is that it is absolutely crucial to keep contact force to a minimum. Given the high speeds that this seal must operate at, the seal should only lightly contact the end of the rolls. Many trials and thoughts finally led to a design that would maintain light and controllable contact pressure under all chamber conditions. The design of this seal loading system is shown below.

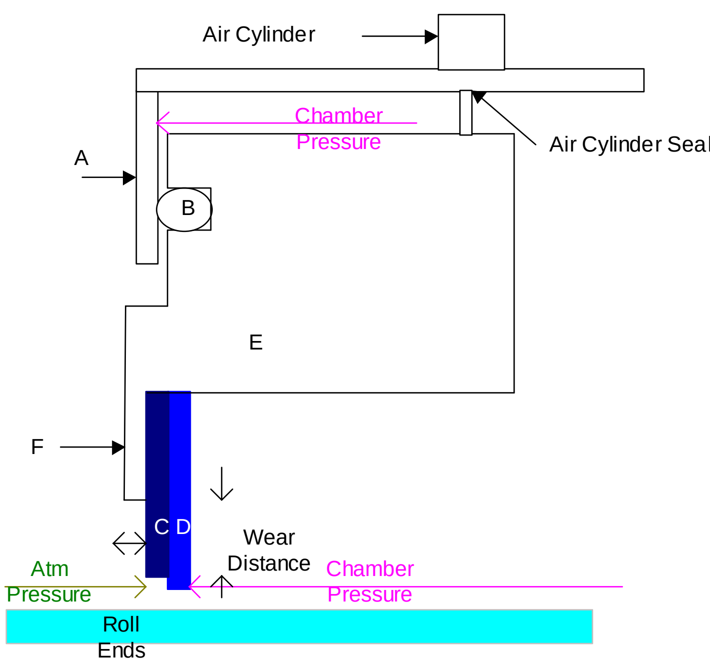


Figure 12 – Controlled Force End Seal – US Patent 6,589,394 –July 8, 2003

The above drawing shows a cross section view of the dog-bone seal, perpendicular to the roll ends. As shown, the sealing elements, C-D are forced into the roll ends which blocks air from leaking out of the chamber. Element C-D is the closed loop dog-bone seal described earlier.

In this drawing, the dog-bone seal is attached to piston E which can travel up and down in cylinder A. The unique feature of cylinder E is that it applies essentially no net force on the dog-bone seal no matter what chamber pressure is used or how it varies. The reason for this is that chamber pressure is applied both above and below the piston, so the piston exerts no net force on the seal. Of coarse some sealing force is needed, so the air cylinder shown is used to apply the small amount of pressure needed to effect sealing. With this arrangement, it becomes possible to accurately and precisely control sealing pressure at the low levels needed for good seal life. It also becomes possible to retract the seal for maintenance.

Another conclusion from Archard law is that we need materials that have good wear characteristics. From our many trials we settled on the use of carbon fiber and PTFE in the design of the seal to give us long life.(C and D respectively in Figure 12) To construct our seal designs we found composite technology used by the aircraft industry to work best.

Archard’s law also states that best wear is obtained if hard surfaces are used for the seal and the roll ends. As described above, there is no problem using hard surfaces for the seal, but it’s another matter to install hard surfaces on the roll ends of the cluster press. The problem comes from having a soft cover on the cap rolls. The soft roll cover is needed so the cap roll can effectively seal to the fabrics as they pass through the entrance and exit nips for the chamber. With the soft roll cover comes soft roll ends that will bulge when the rolls are forced together. Pushing the seal into these soft roll ends causes rapid wear and leaks rapidly develop.

To present a hard, flat roll end to the seal, yet still use soft roll covers was a problem that kept us up many nights, until the author hit upon a method for “Cross-Directional Interlocking of Rolls…” US patent # 6,562,198. Schematically, a cross section of the interlocking roll ends is shown below.

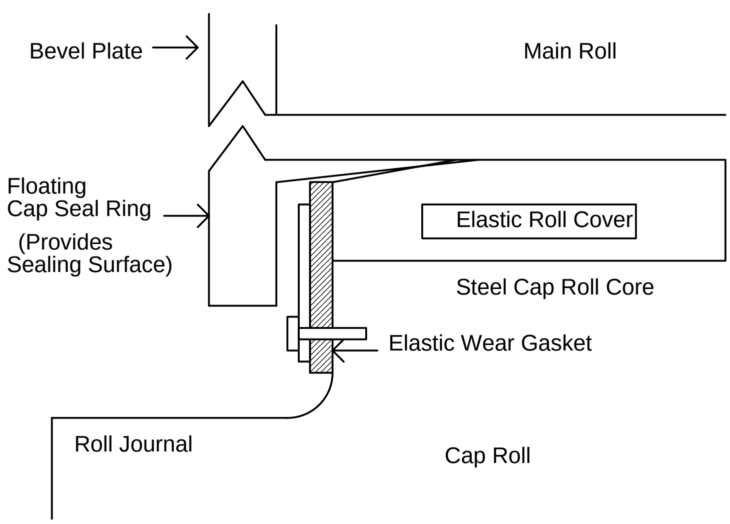


Figure 13

In this design, ‘bevel plate’ rings are mounted rigidly to the ends of main rolls. Next, ‘floating cap seal rings’ are installed over the ends of the cap rolls. These seal rings have two functions. First, in the nip, the seal rings interlock with the main roll bevel plate due to their interlocking design. With all rings interlocking, a planer surface is created which the dog-bone seal can seal with. This planer surface is made of metal or other hard materials, which is ideal for producing a long life, low leakage seal when contacted by the dog-bone seal described earlier.

The second aspect of this seal ring is that it produces a long lasting, low wearing seal with the cap roll. Since the inside of the seal ring and outside of the cap roll has similar surface speeds, the wear rate is low between the ring and the cap roll elastic surface.

The floating rings are not rigidly attached to the cap roll, so they must be guided and loaded as a separate element as shown in figure 14. The rings are slightly larger than the cap rolls so they only make contact with the cap roll in the nip area. Outside the nip, the rings separate.

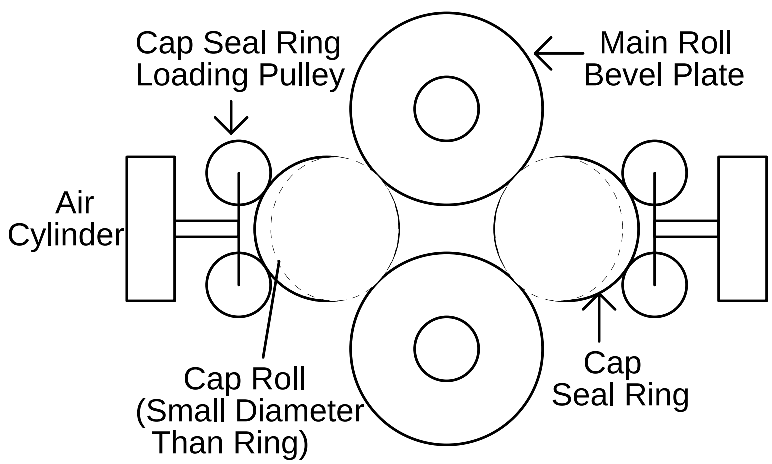


Figure 14

The critical system of seals and rings illustrates our ongoing development strategy effort since the early days of the project – even before DOE. These elements were first tested in small scale testers where experiments can be quickly done at low cost. From here, tests were done on our lab machine, and after the bugs were worked out, they were scaled up to full size for use on our 1m machine. In the case of the dog-bone seal, there was an intermediate step to test them on a full size seal tester shown in figure 15. Even the testers underwent improvements during this project. The tester shown in figure 15 is the 3rd generation tester we built to test seals.

Through out this project, we always found it easier to build and test new ideas in the smallest scale possible. With this new papermaking process, came lots of new ideas which begged to be tested. The health of the project required that we test the best new ideas as quickly as possible and the only way to do this was on small scale. From our successes in small scale comes the confidence and experience to decisively proceed to larger scale.

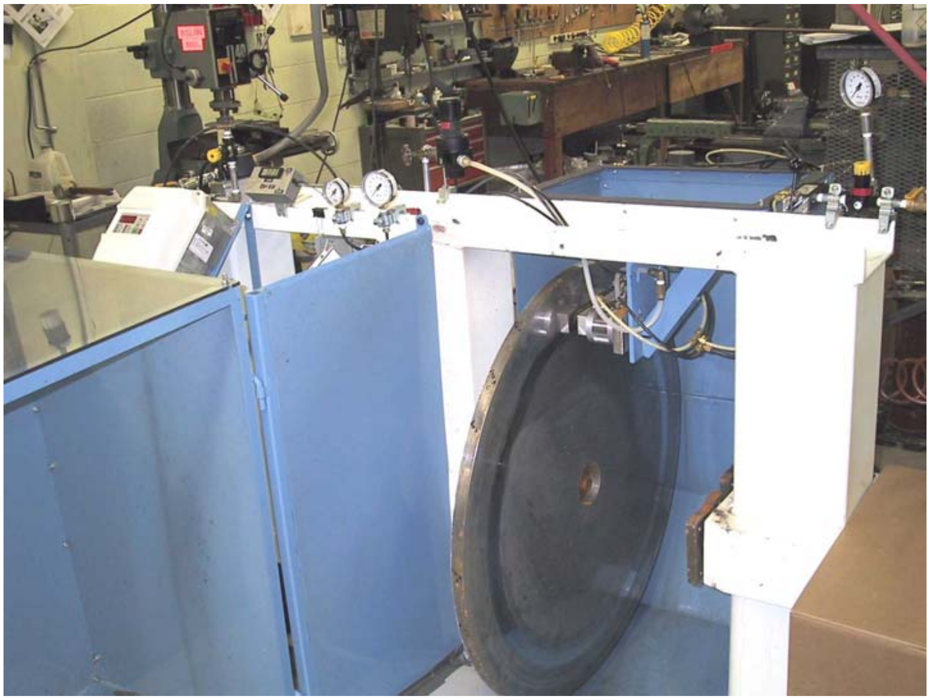


Figure 15 This tester allows us to test small and full size seals at commercial speeds.

Starting Up The 1m BCP

As one can see, a lot of development effort was needed before we could design the 1m press stand. Using our strategy, we encountered most of our problems in small scale and solved them there before proceeding to large scale. By using the lab machine to lead the development effort, costs were kept to a minimum, and possible solutions could be tested quickly. Often it took many trials to find good solutions, but we learned a lot in the process and developed a feel for the new process we were creating. When it came time to start up the 1m machine, we were well prepared and could recognize many problems from our experiences on the lab machine.

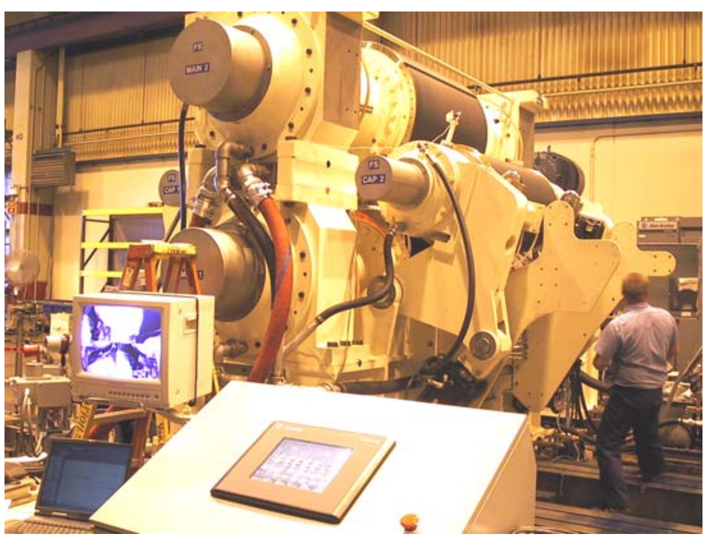


Figure 16 Photo of 1m BCP with Touch Screen Control System in Foreground

When our 1m machine was finally started we found our most unfortunate oversight had little to do with the new elements of our process, rather we found the drive motors were too small!

To determine the drive power requirements, we had instrumented our lab machine to measure the drive loads. Based on these measurements, the drive motors were sized for the 1m machine. But when the press was started, we quickly found out that there was not enough torque from the motors to run the press at any substantial speed or pressure. If either speed or chamber pressure was increased, the torque requirements increased and this would cause the motors to over load. After investigation, it was determined that indeed, the power requirements to rotate the roll covers were correctly sized based on lab measurement. The big problem however is that we didn't properly account for the added the drag from the bearing loads. As it turns out, as bearing loads increase, it takes increasing power to turn them. Intuitively one would think that the bearing turning load would be small, but we found out and as verified by manufacturer data, these loads are much larger than any other drive loads we anticipated. Due to the high drag from the bearings it was simply not possible to run our press with the two 40 HP motor drives we had purchased. It was necessary to purchase new motors and new electronics to drive them in order to run at design speed. It took several months to find this problem, order replacements and to get them installed. Such a problem on our lab machine would have been fixed in 1 month, but the game is different with large machines and it takes lots of time and money to fix such problems.

Through the rest of the DOE contract period, the 1m pilot press stand was run with a very low drive capability as described above. With these low powered drives, we proved that the press could run for 8 hours a day for 5 days a week for 4 weeks at a speed of 1000 fpm and a chamber pressure of 10 PSI. This proved that we can seal and maintain pressure in the chamber. However, with the initial drives we could not operate at commercially interesting higher speeds and pressure. The best we do to verify check high pressure operation was to pressurize the chamber without the rolls running. In this static position the press attained full supply line pressure of approximately 75 PSI with no special modifications to the sealing system.

All the above test conditions were run without a fabric present. That is to say, we were testing the sealing ability of 4 rolls and the end seals. In this condition, the only possible air leakage is around the seals and between the rolls. These leaks were controllable and considered minor – a major hurtle for this process.

With the need to re-do the drive system for this press and its added cost beyond the DOE allocation, it was deemed necessary to close out the project. All but one objective had been reached. We had not reached the objective of putting hand sheets through the press. To put paper hand sheets through the press, we would have to re-do the drives, deal with the fabric runs, and we would have to vent one of main rolls. It did not make sense at that time to vent the main roll and add the fabric runs.

Once the main roll is vented and the fabrics runs are installed there is another path for air to escape from the chamber. This additional air flow path is through the fabrics and into the vented roll. The addition of this flow path makes it impossible to isolate and study seal and nip leakage. We decided we really wanted to know how our seals were working for the long term, so we had to decline the last objective of passing hand sheets though our press.

By this time in the project, we had passed hundreds of hand sheets through our smaller lab press and could do this on a daily basis anytime we wanted. It seemed poor logic to pass a few sheets though the 1m machine and forsake proving the seals. Based on these factors we were convinced our time was better spent proving out our large scale sealing system instead of making more hand sheets.

Patents Disclosures

During this development effort, several patents were applied for. Under the patent waiver agreement granted to Voith for this project, Voith retains most rights for these patents. Voith has duly notified DOE of these patent applications as required by the waiver. So far, only two of the applied for patents have issued. The inventions disclosed to DOE are:

"A main roll for an air press of a papermaking machine"
"A controlled-force end seal arrangement for an air press of a papermaking machine" US 6,589,394
"An anti-rewet felt for use in a papermaking machine"
"Permeable membrane"
"Cross-directional interlocking of rolls in an air press of a papermaking machine" US 6,562,198
"Cleaning a semi permeable membrane in a papermaking machine"

Acknowledgements

The author would like to gratefully acknowledge the help and support of DOE and Voith in being allowed to do this research. At the time this research was proposed, industry health was (and still is) on the decline. The normal industry expectance was to reduce research efforts in order to cut costs. Many fine researchers have lost their jobs because of these cost cutting efforts. In the face of this both Voith and DOE had the foresight together to put in seed money for a new untried process. It now appears that their investment is justified. I'm grateful for risk they took and the opportunity to participate in this revolutionary effort. In the future, I hope we can continue to work together toward the common good.

At this writing, there is much interest by several paper companies wishing to help us commercialize our process. It seems certain that one or more companies will invest in further development of this process. This interest is a direct result of our DOE project. With the DOE review process and our industry partnerships, this project gained credibility and momentum that helped greatly toward its success.

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